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ANCIENT WATER TECHNOLOGY: BETWEEN HELLENISTIC INNOVATION AND ARABIC TRADITION

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Résumé – Un réexamen des sources archéologiques et des sources écrites conduit à des conclusions nouvelles en ce qui concerne le niveau de connaissance en technologie hydraulique à la haute époque hellénistique. Après avoir passé en revue les textes de Vitruve, on propose une analyse nouvelle de notre source hellénistique la plus importante, les *Pneumatica* de Philon de Byzance. L'objet de cet article est de montrer d'abord que la traduction arabe est probablement authentique et ensuite de replacer ce texte dans le contexte de la technologie antique relative à l'eau. À l'aide d'autres sources inconnues par ailleurs, on démontre qu'il existe une continuité complète depuis les innovations hellénistiques en matière de technologie hydraulique, transmise d'est en ouest par les savants arabes.

Abstract – A reappraisal of the archaeological and written sources leads us to new conclusions regarding the standard of knowledge in water technology in early Hellenistic times. After a general review of the texts of the well-known author Vitruvius follows a new analysis of our most important early Hellenistic source Philo of Byzantium and his “pneumatica”. The aim of this article is first to demonstrate that the Arabic translation most probably is authentic and secondly step to place this text in the context of antique water technology. Along with some hitherto unknown sources it demonstrates an unbroken continuity of antique water technology with Hellenistic innovation being handed down from the orient to the occident by Arab scientists.

خلاصة – تقودنا إعادة دراسة وتفحص المصادر الأثرية والمصادر الكتابية إلى استنتاجات جديدة فيما يتعلق بمستوى المعرفة في تكنولوجيا المياه خلال العصر الهلنستي القديم. ونقترح هنا بعد مراجعة نصوص فيتروفي Vitruve تحليلًا جديدًا لأهم مصدر هلينستي لدينا وهو *Pneumatica* لفيلون البيزنطي. والغاية من هذه الدراسة أن نبرهن أولاً أن الموروث العربي هو موروث أصيل على الأغلب ومن ثم أن نعيد وضع هذا النص في إطار التكنولوجيا القديمة المتعلقة بالمياه. ونبين بمساعدة مصادر أخرى غير معروفة سابقاً وجود استمرارية منذ الاختراعات الهلنستية في مجال التكنولوجيا المائية، والتي نقلها العلماء العرب من الشرق إلى الغرب.

The extraordinary wealth of Egypt in Antiquity is based on high agricultural yields. The basis of Egyptian agriculture and with that the guarantee for the wealth of Egypt however was the forced use of irrigation. Some years ago it could be proved that a big water reservoir had existed in the Fayum which had probably been built in early Ptolemaic times.¹ This fund led to a much better understanding of the huge cultivation programme of the early Ptolemies. They developed new cultivation areas for Greek settlers on a large scale especially in the Fayum.² They should improve further the wealth of Egypt by means of agricultural yields.

1. GARBRECHT & JARITZ 1992 (2), p. 38-254.

2. ROSTOVITZEFF 1922; SCHNEBEL 1925; LEWIS 1986; SCHÜRMANN 1991, p. 115-127; BOWMAN & ROGAN 2001.

In a papyrus³ which the minister of finance Apollonios sent to the manager of his land Zenon in the Fayum on the 27.12.257 BC he ordered him to sow the fields a second time. But a second harvest was only possible under two conditions: enough water and efficient water-lifting-devices.⁴

After the existence of the big water reservoir has been proved the question now is whether these powerful water-lifting-devices had also existed. This leads us to the central point of my paper: which level did water technology have in early Hellenistic times?⁵

An Akkadian seal of the 3rd millennium BC already showed a shaduf. After 2000 BC we also find it represented in Egyptian art (**fig. 1**). Compared with the shaduf the water-wheels, the bucket-chain and the pumps possess a greater efficiency and could lift the water to higher levels.⁶ But whereas the existence of the shaduf is proved clearly, the origin and date of the water-wheels and the connected water-lifting-devices is controversial. Our main source is Vitruvius who writes about a number of water-lifting-devices in his 10th book.

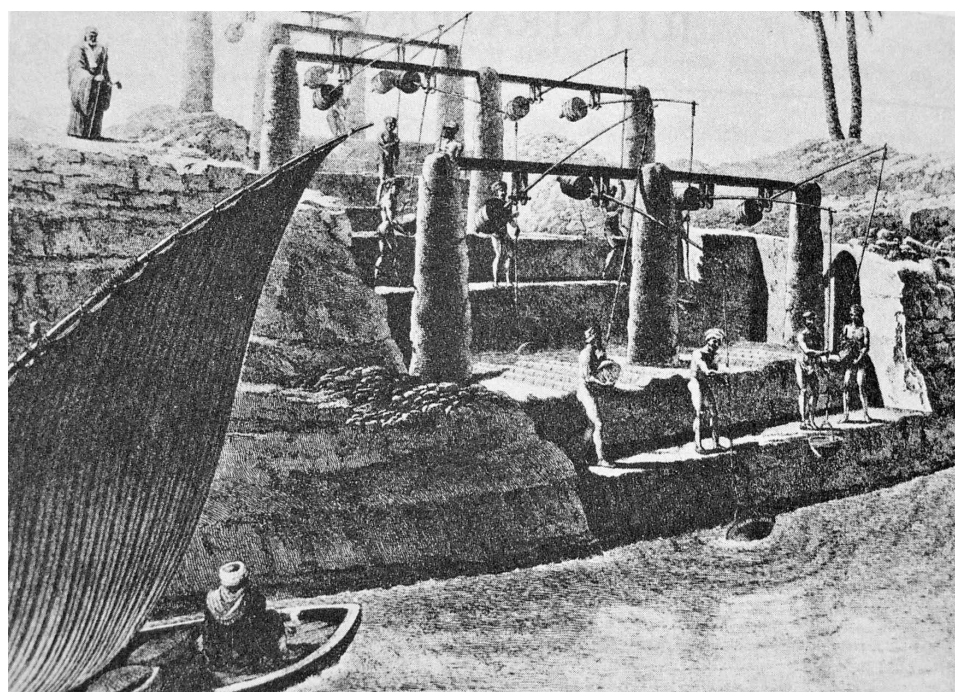


Figure 1 : A shaduf from *Description de l'Égypte* (1822-9), II Pl. 6.

First he mentions the so-called *tympanum* i.e. the wheel with compartmented body. Unfortunately, neither graphical representations nor archaeological remains have so far been identified yet. Therefore we have to rely on Vitruvius's description.⁷

In contrast to the *tympanum* the water-wheel with compartmented rim consists of an open spoke wheel which carries a hollow rim. This rim is divided into compartments with openings at the outer sides. Because of the lighter design the diameter and thus the lifting height are unequally higher. At the same time the compartments are smaller resulting in a reduced quantity of lifted water. These kinds of water-wheels have survived in large numbers in Roman mines.⁸

3. *Papyrus Cairo Zeno*, 27.

4. SCHENKEL 1978, p. 22 sq.

5. OLESON 1984; SCHIOLER 1973; SCHÜRMANN 1991, p. 94-112.

6. BONNIN 1984, p. 251-286.

7. Vitruvius, X, 4, 1-2; see the reconstruction in LANDELS 1979, p. 77 fig. 15.

8. OLESON 1984, p. 196, 205sq., 219sq., 251-259, 276-279.

The sakija (**fig. 2**) is a variation of the water-wheel. Pots for water-lifting are tied to its rim. It is powered by a cogwheel mechanism with yoked draft animals resulting in high efficiency. Furthermore is the use of pottery a cheap solution in a region where wood is scarce. That is the reason why the sakija was superior to the other water-wheels and exists nearly unchanged till today.⁹

To complete this presentation of antique water-lifting-devices also the Archimedean screw and the force pump of Ctesibios of Alexandria should be mentioned.¹⁰

As Vitruvius¹¹ tells us, there existed one possibility to lift water from greater depth. If a bucket-chain is wound around a turning shaft instead of a water-wheel, the height for lifting water can be increased through the length of the chain.

The shaduf and the Archimedean screw are described in the sources as *kiloneion/tolleno* and *kochlias/coclea* and can easily be identified. But the terminology of the other water-lifting-devices is much more obscure.¹² They are called *mechane* or *organon*, which are unspecific terms. Probably every water-wheel is a *mechane/organon* while not each *mechane* or *organon* means a water-wheel. We could only be sure about this if important components such as draft animals or cogwheels were mentioned.

This is the difficulty when we try to interpret the sources, especially the papyri. One papyrus contains the petition of a colonist at Apollinopolis for an audience with Ptolemaios II. He proposed to show the king a *mechane* that will save the land which has not been inundated for three years.¹³

Vitruvius seems to be our oldest source. But do really no Hellenistic sources exist which could tell us something about origin and date of the water-wheel? The earliest and most controversial source mentioning the water-wheels is the treatise on pneumatics by Philo of Byzantium.¹⁴ Philo was one of the most famous mechanics in Antiquity and lived in the second half of the 3rd century BC. He wrote a *mechanike suntaxis*, a compendium of mechanical technology (in several books).¹⁵ Parts of this compendium are preserved, some of them in Greek, while others are lost and only mentioned in other books, for example the book about the “miraculous instruments”. In his book Philo writes about the different kinds of ancient pneumatics, hydraulics and mechanics. In the last chapters of the *Pneumatica* he presents several automata in this context referring to water-wheels.¹⁶ Thus their existence seems to be verified for the 3rd century BC. But apart from some Latin fragments (chap. 1-21) the *Pneumatica* is only preserved in an Arabic translation. The greater part and especially the chapters on water-wheels are considered to be Arabic additions and not belonging to the original Greek text. Carra De Vaux, whose



Figure 2 : A sakija, photo coll. of the author.

9. MÉNASSA & LAFERRIÈRE 1974.

10. Vitruvius, X, 6-7; OLESON 1984, p. 291-325 fig. 13-14, p. 27-28, p. 36, p. 43-46, p. 48-49, p. 67-71, p. 78-79, p. 86, p. 101, p. 110-111, p. 141, p. 149.

11. Vitruvius X, 4, 4.

12. REIL 1913; CALDERINI 1920a, p. 620-31; CALDERINI 1920b, p. 309-17; SCHNEBEL 1925; see also the collection of sources in the book of OLESON 1984, p. 15-171.

13. P. Edfou 8; see LUKASZEWICZ 1996, p. 91-98.

14. CARRA DE VAUX 1903.

15. DRACHMANN 1948; SCHÜRMANN 1991; AMEDICK 2003; FOLKERTS 2000.

16. Philon, *Pneumatica*, chap. 61-63.

translation of the Arabic text is still definitive, couldn't identify one single chapter, which was not authentic and of Greek origin. This led him to the conclusion that the Arabic translation corresponded to the lost original.¹⁷ This opinion was widely refused. Prager, who published an English translation in 1974¹⁸, analysed the text using formal criteria such as style and structure and compared it with the preserved Greek books by Philo. Since Prager had no knowledge of Arabic his work is based on the English translation of a French translation of an Arabic translation of a lost Greek original.¹⁹ He stated "quality differences" since Philo didn't concentrate on pneumatics as his predecessors had done.²⁰ As Philo's book is the oldest preserved on pneumatics what sense makes the reference to predecessors in this case? We should first define what pneumatics comprised in Antiquity before judging if some parts are not pneumatic. Prager referred to arguments in an article by I. Hammer-Jensen of 1910.²¹ She compared the Arabic text with the "authentic" Latin translation which contains only the first twenty chapters. This Latin fragment Prager describes as being "effective, didactic, theoretical and purely pneumatic"²² while he considers the others, preserved only in Arabic, as being exactly the opposite and containing mainly *automata*. But can we really see a clear break in the texts between Greek theory and Arabic practice? The first sixteen chapters are about the theoretical basis of air- and water-technology. But then follow both in the Latin and in the Arabic text *automata* as demonstrations which serve as "trickvases" for entertainment and not for science. Chapter 17 begins with the sentence: "Afin que la vérité de notre théorie soit établie par de nombreux exemples et qu'on connaisse la construction des machines", meaning that if we assume a break in the *Pneumatica*, we would also find it in the Latin text. Prager and Hammer-Jensen pointed out that the following chapters are in a bad condition. The instructions are partly incomprehensible. Because they argue that this wasn't so in the Greek original and it also couldn't be their own fault, there's only one explanation for the non-working-*automata*: it was the mistake of an Arabic author.²³ Every badly described *automaton* would be invented by Arabic authors with the paradoxical explanation that they had also worked on water-technology. A. G. Drachmann²⁴ in contrast based his arguments against the authenticity of the *Pneumatica* on its content saying that a trick vase constructed by Philo for the symposium couldn't be Philonic, because it hasn't got the shape of a crater and so the wine couldn't be mixed in it.²⁵ But of course the wine could have been diluted beforehand. In several cases Drachmann deduced from the allegedly typical Arabic shape of the vessel that the chapters were of Arabic origin. Recent surveys show that this type of vessel already existed in Greek times.²⁶ Some chapters or rather *automata*, which he excluded employ the principle of the force pump of Ctesibios (fig. 3) and can therefore most probably be considered as Philonic.²⁷

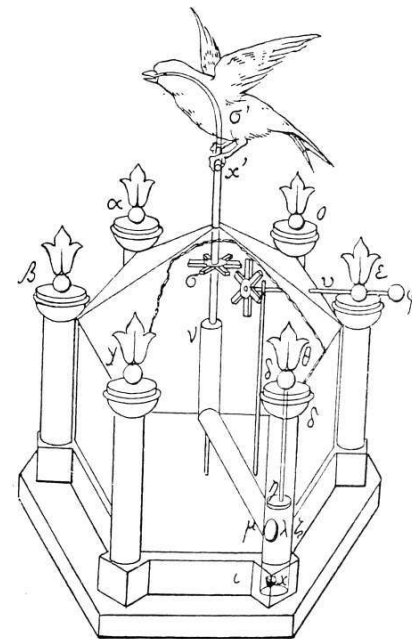


Figure 3 : The force pump of Ctesibios
(CARRA DE VAUX 1903, p. 171).

17. CARRA DE VAUX 1903, p. 35.

18. PRAGER 1976.

19. PRAGER 1976 VII.

20. PRAGER 1976, p. 39.

21. HAMMER-JENSEN 1910, p. 413-27, p. 480-503.

22. PRAGER 1976, p. 66.

23. HAMMER-JENSEN 1910, p. 416; PRAGER 1976, p. 67.

24. DRACHMANN 1948.

25. DRACHMANN 1948, p. 60.

26. DRACHMANN 1948, p. 62; PRAGER 1976, p. 163 ed. 486.

27. Kap. 35, 37 und 38; see PRAGER 1976, p. 190 sq.

Very controversial are the last chapters, which contain allusions to the water-wheel. After it couldn't be proved that some chapters are of Arabic origin maybe it could be proved that the important chapters are indeed of Greek origin. Chapter 60 (**fig. 4**) for example presents the construction of an artificial whistling bird. It was challenged that this chapter and the entire last part of the *Pneumatica* was of Greek origin. But as Vitruvius tells us even Ctesibios has constructed whistling birds.²⁸ So it is most likely of Greek origin.

The Arabic text mentions a “siphon égyptien” in chapter 60. The term is mentioned only there and in chapter 6. But chapter 6 is preserved only by the Latin text while the Arabic one has a gap. How could the Arabic translator know this term? He couldn't refer to chapter 6 in his own text. So he must have used at this point the same source for his translation as the Latin translator. As nobody questions that the Latin translator based on the Greek original we can assume the Arabic translator did the same.

If chapter 60 is without doubt Philonic and the next chapter refers to it, we can be sure that this chapter is also authentic. The here explained construction (**fig. 5**) of a “whistling wheel” is said to correspond to the “tambours qui servent à irriguer”. The next chapter 62 (**fig. 6**) deals also with a “whistling wheel” but with pots on the rim instead of compartments. In this case the description is incomprehensible but this appears to be due to important parts of the construction having been left out rather than not having understood them. The last chapter 63 (**fig. 7**) describes a “roue hydraulique pour les ablutions et les purifications placée dans le voisinage d'une

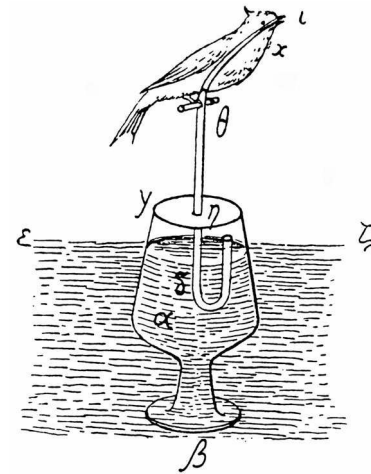


Figure 4 : An artificial whistling bird (CARRA DE VAUX 1903, p. 200).

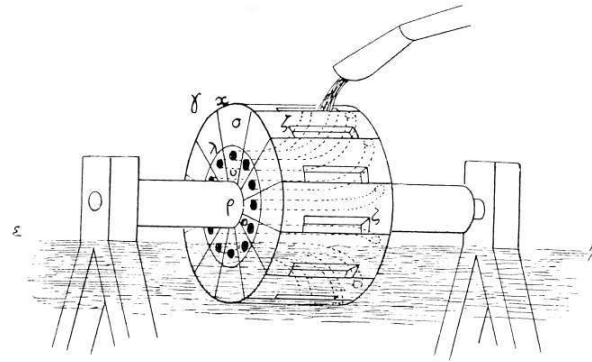


Figure 5 : A “whistling wheel” (CARRA DE VAUX 1903, p. 202).

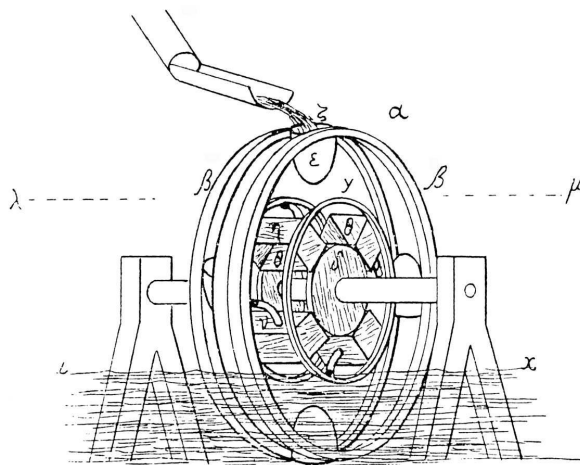


Figure 6 : A “whistling wheel” with pots (CARRA DE VAUX 1903, p. 204).

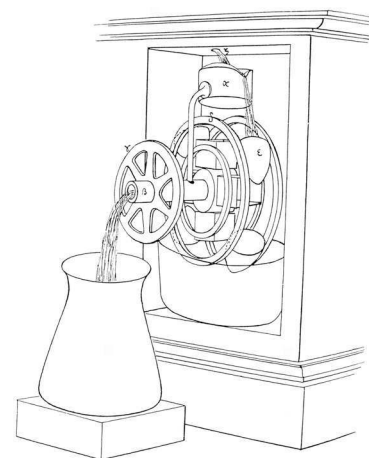


Figure 7 : Hydraulic wheel in a square copper container (CARRA DE VAUX 1903, p. 206).

28. Vitruvius X 7, 4.

mosquée ou d'un temple" made of copper and installed in a square copper container. Philo's wheel dispenses water by turning it but the reconstruction of the mechanism is difficult. Also Hero of Alexandria mentions the "temple-wheels" which are installed in the temples of the Egyptians near the entrance. The wheels are made of copper and turned by the faithful who believed that the copper will clean them.²⁹ Could an Arabic author after reading Hero have written the chapter in Philo's book like Prager, Hammer-Jensen and others thought? Two years before Carra de Vaux's translation was published appeared an article by W. v. Bissing.³⁰ In this article he describes (fig. 8) a small box made of copper, 9 cm long, 4 cm high, 6 cm deep, which he had come across in Thebes. In the box is fastened a copper disc, which protrudes from the box. Bissing thought it to be from the Late Period. If we compare the ancient sources for the temple-wheel, Philo is the only one who mentioned that the wheel of copper is fastened in a box of copper like the one preserved. How should an Arabic author know that after reading Hero who didn't mention the box of copper? It seems now very probable that the last chapters are original Philonic. The existence of water-wheels in the 3rd century BC is therefore proved.

J. P. Oleson supposed in his definitive book about water-lifting devices that Vitruvius described all water-lifting-devices that existed at the end of the 1st century BC. But what is missing in Vitruvius's text is the animal operated sakija. Oleson's conclusion is that it didn't exist at that time.³¹ How reliable is Vitruvius if we compare preserved water-lifting-devices with his descriptions? Vitruvius³² mentions boxes on the rim of the wheels but the preserved wheels show only a hollow rim and a division into compartments. Also the turning of the wheel by treading men is impossible for the installation in Roman mines. And they aren't made water-tight with pitch.³³ We find another mistake when we look at Vitruvius's description of the bucket-chain.³⁴ According to him the chain is wound over a round axle but the chain would begin to slip when the buckets are filled on one side.³⁵ Even the Archimedean screw shows clear differences to Vitruvius's description.³⁶ The archaeological remains had two helical vanes fixed on a wooden core while Vitruvius speaks of eight. And they are installed at a much flatter angle than Vitruvius tells us.³⁷ Oleson maintained that Vitruvius assumed that these details were known. But somebody who has no experience with water-lifting-devices couldn't build them after Vitruvius's description and an expert wouldn't need it in this form. And why does Vitruvius mention the cogwheels in the chapter about the mill but not in connection with the water-wheels? Should we really believe that until this time nobody had thought about a water-wheel driven by cogwheels? In chapter 6 of his *Pneumatica*, only preserved in Latin, Philo explains: "Will man sie (Wasser) auf einen erhöhten Punkt heben, bedarf es einer geeigneten Vorrichtung. Das wissen manche nicht, die Wasser nur von solchen Orten, wie den Brunnen, nur mit

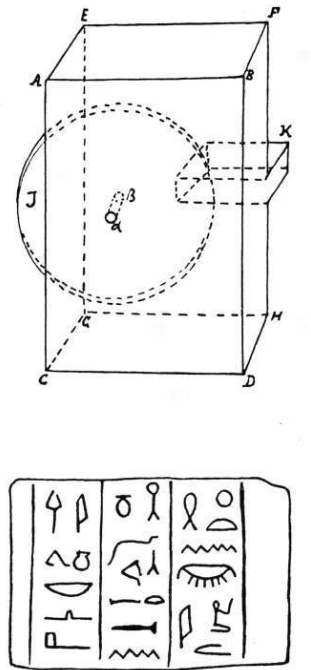


Figure 8 : Copper box in Thebes from VON BISSING, ZÄS 39, 1901, p. 144.

29. Heron I 32, II 32.

30. V. BISSING 1901, p. 144 sq.

31. OLESON 1984, p. 354 sq.

32. Vitruvius X 4, 3.

33. See OLESON 1984, p. 116-127, p. 137 sq., 152 sq., 154 sq., 185 sq.

34. Vitruvius X 4, 4.

35. See Philon, *Pneumatica* Chap. 65, who offers a solution to this problem and also LANDELS 1979, p. 86-90.

36. Vitruvius X 6.

37. DRACHMANN 1963, p. 154; OLESON 1984, p. 296-298.

Schöpfemern zu entnehmen verstehen, oder mit anderen Geräten, die von Tieren bewegt und gezogen werden oder falls etwa die Entnahme mit Hilfe von Wasserrinnen erfolgt, die aus einem Fluss oder einer Quelle, welche bergab strömen, hergeleitet werden. Soweit dies möglich ist, wollen wir im Folgenden dies viel gründlicher dartun, ...³⁸ Only one water-lifting-device existed which was moved by animals – the sakija. Vitruvius remains of course our most important source because of his detailed descriptions. But this shouldn't keep us from reading him critically. And it surely doesn't mean that something not described by Vitruvius didn't exist.

Unfortunately the situation regarding the archaeological remains is difficult. The preserved examples come mainly from Roman mines which showed better conditions for the preservation of organic materials than agricultural contexts. But Roman examples don't help to solve the problem of the Hellenistic water-lifting-devices. However there are some examples from Hellenistic times.

A formerly isolated find from Egypt can now be confirmed. In 1927/28 an archaeological expedition discovered a canal system near Karanis in Northern Fayum.³⁹ Thanks to coin-finds the system could be dated to the times of Ptolemy II. It was probably part of his cultivation programme. A round reservoir was part of this canal system. The stones for the reservoir came from a nearby quarry which is also dated by a coin of Ptolemy II. The bottom of the reservoir was covered with a thick layer of ceramics (fig. 9). At the bottom of this layer 15 vessels were found which could easily be identified as pots from a sakija.

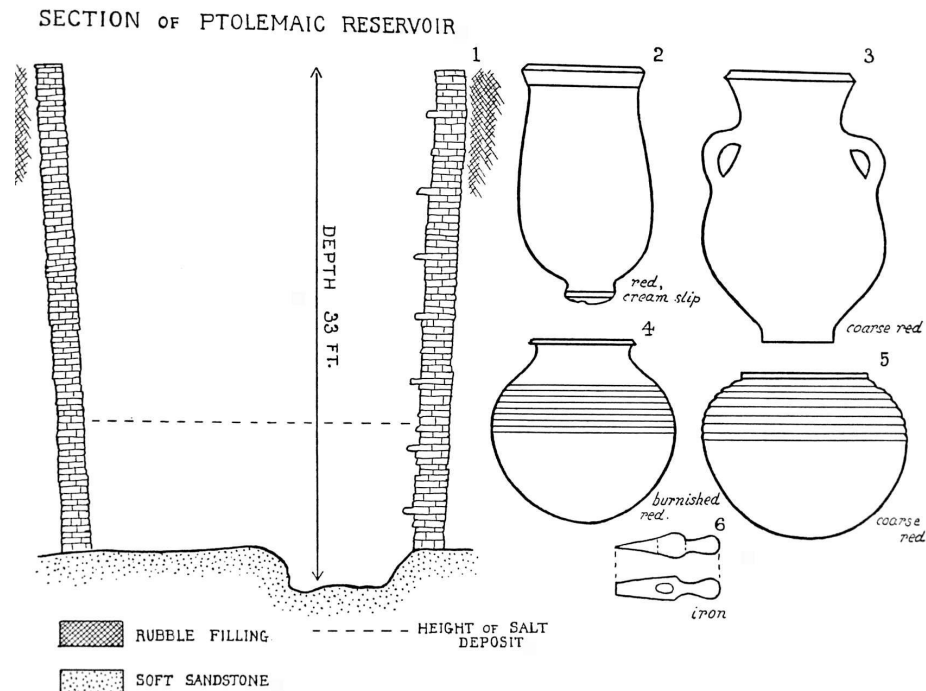


Figure 9 : Ptolemaic reservoir and ceramics near Karanis
(GARDENER & CATON-THOMPSON 1934, Pl. 98).

38. « quas cum quis voluerit motu innaturali elevare ad locum altum, opus est ingenio competenti: quod a nonnullis ignoratur nescientibus aquam ex locis huiusmodi extrahere nisi cum situlis, ut fit ex puteis, vel cum aliis instrumentis, que moventur et trahuntur ab animalibus, vel si forte fiat extractio per rivos currentes vel fluminis vel fontis ad ima descenditis ». (*Liber Philonis De Ingeniis Spiritualibus*, Herons von Alexandria Druckwerke und Automatentheater I, ed. W. Schmidt, 1899).

39. GARDENER & CATON-THOMPSON 1934.

An extraordinarily rich decorated grave in Alexandria contains a painting, which shows a *sakija* with oxen (**fig. 10**).⁴⁰ The grave was completely plundered. The excavator thought because of the style of the painting that it was made at the end of the 1st century BC.

In Pompeii several installations for bucket-chains are preserved because of the unique conditions.⁴¹ The wooden parts of course are lost but the rooms where the devices were installed still exist. A long narrow room for the tread-wheel in combination with a large well shaft and basins for water-storage were found in two baths, the Stabian Bath and the Forum Bath and in one private house. The installation in the Stabian Bath dates from the 2nd century BC⁴² while the others were built at the beginning of the 1st century BC.⁴³

At the excavations in the harbour area of Cosa in Italy remains of a fountain house were found.⁴⁴ In the house the excavators discovered the remains of a bucket chain. House and bucket chain had existed from the first quarter of the 1st century BC. The bucket-chain raised the water 5 m high and was driven by cogwheels with animals.

Maybe Philo offers a solution to the problem when these water-lifting-devices were developed. The Arabic scholar Omar Ibn al-Kindi (AD 970) remarked about Philo that he was experienced in the construction of water-wheels and mills.⁴⁵ Since no book from Philo about water-wheels exist this seems to be an invention by al-Kindi.⁴⁶ But there's a way to find an answer to this question. All preserved books of Philo begin with a dedication to his friend Ariston: *o phile mou ariston*. The fragments of the *Pneumatica* illustrate what happened to this phrase through translation⁴⁷. In the Arabic texts the phrase was changed from *o phile mou ariston* to *Muristom*, *Ristum* and so on. But Arabic sources mention in several cases a Greek scholar named Muristos who was supposed to be a scientist like Euclides, Pythagoras and Archimedes.⁴⁸ Because a Greek scholar of this name didn't exist there is only one solution. The author's name normally appeared at the end of the book and got lost very easily. The dedication at the beginning was preserved but *o phile mou ariston* was changed to *Muristos*. So eventually *Muristos* was considered to be the name of the author.

From a remark by Philo Carra de Vaux has deduced that he had also written a book on "wonder-instruments".⁴⁹ According to Carra de Vaux this term stands for water-organs. Because of this he believed that a book by Philo on water-organs had existed. And fortunately there are reports by Arabic scholars saying: "Muristos, man sagt auch Muritos, war ein griechischer Gelehrter, ein praktischer und

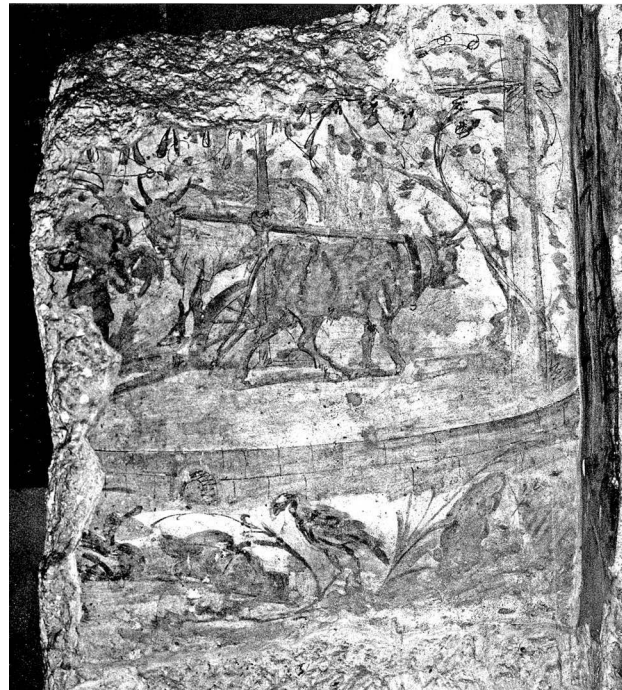


Figure 10 : Funerary painting from Alexandria
(photo coll. of the author).

40. RIAD 1967, Tab. I-V; VENIT 1988; VENIT 1989.

41. PEMP 1940.

42. ESCHBACH 1979, p. 30-34.

43. OLESON 1984, p. 246 sq.

44. OLESON 1987, p. 98-128, p. 274-281; OLESON 1984, p. 201-204.

45. WIEDEMANN & HAUSER 1918a, p. 123.

46. PRAGER 1976, p. 25.

47. CARRA DE VAUX 1903, p. 33 et 38 sq.; PRAGER 1976, p. 46 sq. Chart 3.

48. WIEDEMANN & HAUSER 1917-18, p. 141 sq.

49. CARRA DE VAUX 1903, p. 37.

erfindungsreicher Mann. Er schrieb ein Werk über das Orgel genannte Instrument, es ist ein Instrument, das man auf 60 Meilen hört.”⁵⁰ Since Muristos is identical with Philo, the assumption of Carra de Vaux can be confirmed. A second text in Oxford⁵¹ begins with the words: “Oh mein lieber Maristun, ich will dir erklären, wie man die Wasseruhren, die Bewegung durch die Kugeln und anderes konstruiert”.⁵² And in fact it contains the construction of a water-clock which is very similar to a clock described by Vitruvius as the clock of Ctesibios.⁵³ Books of Philo about water-clocks and water-organs can thus be reconstructed through Arabic tradition although they are tributed to Muristos who infact is identical with Philo. But an-Nadim said in his *al-Firist* that this Muristos had also written a book about water-wheels.⁵⁴ The first isolated remark by al-Kindi that Philo had written a book about water-wheels can thus be confirmed. It’s very unlikely that two authors would be wrong when independently maintaining that Philo/Muristos had written about water-wheels. Apart from Muristos’ description of a water-clock the text in Oxford contains some chapters about water-lifting-devices which maybe go back to a lost book by Philo. Through this argumentation two hitherto unknown texts by Philo about water-organs and water-clocks could be made accessible. Even if the text about the water-organ is clearly altered by the Arabs it contains an important information. The water-organ was, maybe in a changed form, still the model for the one made for a king of the land of the Franks in the 9th century AD. The only king who received a water-organ from Arabia was Charlemagne from Harun ar-Rashid around AD 800. Together with the water-organ he received a water-clock which looked very similar to the one described by Philo/Muristos and also by Vitruvius as clock of Ctesibios.⁵⁵ This demonstrates that a continuity in antique water-technology existed over a period of 1000 years. Hellenistic innovations maintained through Arabic tradition were in this way handed down from the Orient to the Occident.

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